ERDC/GSL TN-14-2
August 2014

Review of Instrumentation and Monitoring for USACE Levees

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PURPOSE: The purpose of this U.S. Army Engineer Research and Development Center-Geotechnical and Structures Laboratory (ERDC-GSL) technical note is to identify and review effective technologies related to the remote monitoring of earthen structures (dams and levees).

INTRODUCTION: Extreme loading events considered here are primarily flood loading and, to a lesser extent, seismic loading from extreme earthquake events. The U.S. Army Corps of Engineers' (USACE) guidance has been consistent on instrumentation requirements for the safety of its dams and described in various engineering manuals (USACE 1981, 1987, 1995a, 1995b, 2004, 2011). Therefore, it is appropriate first to summarize the guiding principles involving instrumentation of USACE water control facilities (USACE 2011).

> "All USACE dams and other water control facilities are required to have a level of instrumentation that enables proper monitoring and evaluation of the structure during the construction period and under all operating conditions. Instrumentation systems are also expected to furnish data on structural behavior for application to future designs. Each dam or other water control structure shall have instrumentation to measure hydrostatic pressure, embankment and abutment seepage, foundation underseepage, and displacement of major elements of the structure. Additionally, strong motion accelerometers are to be installed in structures located in designated seismic regions in accordance with USACE (1981).
>
> After a project is operational for several years, scheduled maintenance, repair, and replacement of instrumentation shall be part of the normal plan of operation. Instrumentation shall be properly maintained or replaced, as necessary, in order to obtain accurate and timely data. Readings shall be made at scheduled frequency and shall be properly recorded and analyzed. Detailed information on instrumentation for earth and rock fill dams is given in USACE (2004) and USACE (1995a). Information on instrumentation for concrete dams is given in USACE (1995b) and USACE (1987).
>
> Full reliance should not be placed on instrumentation alone to find problems or to forecast performance, since it is impossible to install sufficient instrumentation to monitor every possible problem area. An extremely important part of the monitoring program is visual observation to determine evidence of distress and unsatisfactory performance (Mahoney 1990). Project personnel shall receive training in basic engineering considerations pertaining to major structures, with procedures for surveillance, monitoring, and reporting of potential problems, and with procedures for emergency operations."

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OMB No. 0704-0188</td></tr>
<tr><td colspan="6">Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</td></tr>
<tr><td colspan="2">1. REPORT DATE
AUG 2014</td><td colspan="2">2. REPORT TYPE</td><td colspan="2">3. DATES COVERED
00-00-2014 to 00-00-2014</td></tr>
<tr><td colspan="4" rowspan="3">4. TITLE AND SUBTITLE
Review of Instrumentation and Monitoring for USACE Levees</td><td colspan="2">5a. CONTRACT NUMBER</td></tr>
<tr><td colspan="2">5b. GRANT NUMBER</td></tr>
<tr><td colspan="2">5c. PROGRAM ELEMENT NUMBER</td></tr>
<tr><td colspan="4" rowspan="3">6. AUTHOR(S)</td><td colspan="2">5d. PROJECT NUMBER</td></tr>
<tr><td colspan="2">5e. TASK NUMBER</td></tr>
<tr><td colspan="2">5f. WORK UNIT NUMBER</td></tr>
<tr><td colspan="4">7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center,Vicksburg,MS,39180</td><td colspan="2">8. PERFORMING ORGANIZATION REPORT NUMBER</td></tr>
<tr><td colspan="4" rowspan="2">9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</td><td colspan="2">10. SPONSOR/MONITOR’S ACRONYM(S)</td></tr>
<tr><td colspan="2">11. SPONSOR/MONITOR’S REPORT NUMBER(S)</td></tr>
<tr><td colspan="6">12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited</td></tr>
<tr><td colspan="6">13. SUPPLEMENTARY NOTES</td></tr>
<tr><td colspan="6">14. ABSTRACT</td></tr>
<tr><td colspan="6">15. SUBJECT TERMS</td></tr>
<tr><td colspan="3">16. SECURITY CLASSIFICATION OF:</td><td rowspan="2">17. LIMITATION OF ABSTRACT
Same as Report (SAR)</td><td rowspan="2">18. NUMBER OF PAGES
6</td><td rowspan="2">19a. NAME OF RESPONSIBLE PERSON</td></tr>
<tr><td>a. REPORT
unclassified</td><td>b. ABSTRACT
unclassified</td><td>c. THIS PAGE
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Specific requirements for instrumentation can be found in the appropriate USACE guidance previously referenced (Engineer Manual (EM)). These EMs are periodically updated, thus the year of reference may change after publication of this review. The most recent guidance should be consulted and reviewed at the USACE website: *http://www.publications.usace.army.mil/USACEPublications/EngineerManuals.aspx*

INSTRUMENTATION AND MONITORING APPROACH: Geotechnical instrumentation can be divided into two categories: in situ determination of soil or rock properties and monitoring of performance during extreme loading events. The second category is where this review will focus. Geotechnical instrumentation can be used to measure deformation, seismic loading, groundwater pressure, total stress in soil, stress changes in rock, and temperature. This information is vital to the design and operation of geotechnical structures, helps ensure the structure performs as intended, and should be used together with a thorough understanding of site geology and groundwater conditions.

PLANNING AND DESIGN: The needs for geotechnical instrumentation are many, and a properly defined and implemented instrumentation plan can help overcome geotechnical uncertainty. Instrumentation can ensure long-term safety by providing data that monitor the performance of the dam or levee over the design life. It can help define the need for and the adequacy of remediation efforts before and after extreme loadings. Placement is vital; the wrong instrument in the wrong location can cause confusion or distract from other issues that may be developing. Each instrument installed on or near a levee must have a specific purpose. A rule of thumb when developing an instrumentation plan is to have a particular question for each instrument that is being installed. Table 1 gives a systematic approach to instrumentation planning and developing a monitoring program.

Planning an instrumentation program should begin with identifying the objective of the instrumentation plan and end with planning how the gathered data will be used and the parameters (i.e., displacement, translation, settlement, rotation, water level or elevation, pore pressure, cracking, volumetric changes, and change in seepage condition) to be studied. Each of these steps is well defined in Dunicliff (1993) and Burland (2012). As part of the planning process, it is important to identify threshold values that, once reached, will trigger execution of a certain preplanned action. Often a traffic light system is used as an analogy for evaluating observed conditions and determining the appropriate response (Table 2).

Defining threshold values is an important aspect of the instrumentation monitoring process, especially when considering a dam with a heavily populated region downstream. Defining the Amber and Red threshold levels should be based on calculated values and tolerances for acceptable performance, given risk associated with downstream conditions.

Remote monitoring plays a vital role when using visual inspection in new construction, but it also plays a vital role during the life of the structure. Data collected from geotechnical instruments allow for timely design and remediation modifications to these structures before failure is reached. The placement and monitoring of geotechnical instrumentation can also yield important information, which can be used to "buy down" risk. The careful review of past and present instrumentation data, in addition to geologic and design information, will aid in the identification of the severity of failure modes that impact geotechnical structures. Once the severity of the failure

modes is identified, remediation efforts can be focused where they are needed most. Early remediation of design issues decreases the cost and time associated with these activities and ensures future performance of the structure. Properly managed data extracted from well placed instruments can validate critical assumptions and address the likelihood of a particular failure mode.

Table 1. Steps in systematic approach to planning monitoring programs using geotechnical instrumentation (Burland 2012).

1	Define the project conditions
2	Predict mechanisms that control behavior
3	Define the geotechnical questions that need to be answered
4	Identify, analyze, allocate and plan for control of risks
5	Select the parameters to be monitored (displacement, water level, pressure etc.)
6	Predict magnitudes of change
7	Devise remedial action
8	Assign tasks for the construction phase
9	Select instruments
10	Select instrument locations
11	Plan documentation of factors that may influence measured data
12	Establish procedures for ensuring data correctness
13	List the specific purpose of each instrument
14	Prepare budget
15	Prepare instrumentation system design report
16	Plan installation
17	Plan regular calibration and maintenance
18	Plan data collection and data management
19	Prepare contract documents
20	Update budget

Table 2. Traffic light system used to define threshold values.

Color	Condition
Green	Embankment is performing as intended and all data are within normal operating ranges
Amber	Data trends are approaching maximum acceptable values. Increased monitoring is necessary, Emergency Action Plan (EAP) should be reviewed, calculations may need to be reviewed, and preliminary agency contacts and contingency measures may need to be initiated if trends indicate that the red threshold may be reached shortly
Red	Indicates that the EAP must be executed and immediate contingency and emergency measures must be taken

Possible failure modes that a dam or levee may encounter include: overtopping, internal erosion (piping) from through seepage or underseepage, rotational slope failure, and liquefaction from earthquakes. During an extreme flood event, the level of water against the embankment may

exceed that anticipated in the original design. This extreme loading could cause water to flow over the embankment and erode material, or cause slope instability, which could lead to failure of the embankment. Internal erosion or piping occurs when seepage water is flowing at a sufficient velocity to carry soil particles with the water. Rotational slope failure can occur when the dam or levee is constructed over a foundation of soft soil. If the dam or levee is built on loose granular material, a seismic event may cause the foundation to liquefy and flow, which may lead to complete or partial failure of the structure. These examples are only a few of the many failure modes that a dam or levee may encounter. There may be unforeseen circumstances or design flaws that contribute to more site specific failure modes. With these failure modes in mind, Dunicliff (1993) made suggestions regarding the proper instruments for monitoring (Table 3).

Table 3. Instrumentation suggestions (Dunnicliff 1993).

Measurement in Priority Order	Recommended Instruments	Additional Instruments for Special Cases
Condition of entire structure	Visual observations	Unmanned Aerial Vehicle (UAV) imagery
Leakage emerging downstream	Leakage weirs Precipitation gage	
Performance of relief wells	Leakage weirs Open standpipe piezometers	
Seismic events	Strong motion accelerographs Microseismographs	
Pore water pressure within the embankment	Open standpipe piezometer Twin-tube hydraulic piezometers	Vibrating wire piezometers Pneumatic piezometers
Vertical movement of the embankment surface	Optic leveling Trigonometric leveling Satellite-based SAR Benchmarks	
Lateral movement of the embankment surface	Electronic distance measurements Triangulation Satellite-based SAR and imagery Horizontal control stations	
Vertical deformation within the embankment	Single-Point and full-profile liquid level gages, overflow type Double fluid settlement gages Horizontal inclinometers Elevation benchmarks	Probe extensometers, installed vertically
Lateral deformation within the embankment	Probe extensometers with multiple induction coil or magnet/reed switch transducers, connected by rods and installed horizontally Horizontal control stations	Fixed embankment extensometers with vibrating wire transducers, or induction coil transducers with frequency output Inclinometers
Total stress at contact between the embankment and a structure	Contact earth pressure cells	

SUMMARY: The current trend in geotechnical instrumentation is the automation of instruments in the field and remote monitoring of these instruments over the Internet. This technique can help decrease the costs associated with retrieving data, but it is still necessary to inspect the system and the site periodically. It is also important to know the reliability of the instruments that are used. Often the simplest instrument will yield reliable results over the lifetime of the instrument. Attention should be focused on reliability of the instrument with time, especially in terms of system electronics and aging.

ADDITIONAL INFORMATION: This technical note was prepared by Dr. Joseph B. Dunbar, Gustavo Galan-Comas, Lucas A. Walshire, Ronald E. Wahl, Donald Yule, Dr. Maureen K. Corcoran, Jose Llopis, and Amber L. Bufkin, U.S. Army Engineer Research and Development Center-Geotechnical and Structures Laboratory (ERDC-GSL). The study was conducted under the Flood and Coastal Storm Damage Reduction Program. This technical note should be cited as follows:

> Dunbar, J.B., G. Galan-Comas, L. A. Walshire, R. E. Wahl, D. Yule, M. K. Corcoran, J. Llopis, and A. L. Bufkin. 2014. *Review of instrumentation and monitoring for USACE levees.* ERDC/GSL TN-14-2. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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